Review Article

Advances in Percutaneous Tricuspid Valve Treatment

Marcio Mendes Pereira,[1] *Maria Estefânia Otto,*[2,3] *Fernando Melo Netto,*[4] *Fernanda Esteves*[5,6]

UDI Hospital,[1] *São Luis, MA – Brasil*
Instituto de Cardiologia e Transplantes do Distrito Federal,[2] *Brasília, DF – Brazil*
Hospital DF Star,[3] *Brasília, DF – Brazil*
Centro Avançado de Diagnóstico em Cardiologia Villas Boas,[4] *Brasília, DF – Brazil*
Hospital Vila Nova Star,[5] *São Paulo, SP – Brazil*
Hospital e Maternidade São Luiz,[6] *São Paulo, SP – Brazil*

Abstract

Tricuspid regurgitation (TR) is a frequently underdiagnosed and undertreated condition, often associated with poor clinical outcomes, particularly in elderly and high-risk surgical patients. As the prevalence of TR continues to rise and traditional surgical methods face limitations, percutaneous techniques have emerged as promising alternatives. This article reviews the latest advancements in the percutaneous treatment of TR, highlighting new etiological and quantitative classifications, in addition to exploring the indications and outcomes of key techniques, including percutaneous edge-to-edge repair and transcatheter valve replacement. Moreover, it discusses the anatomical challenges involved and the vital role of echocardiography in periprocedural planning and monitoring. Based on current data, percutaneous interventions have shown effectiveness in alleviating symptoms and enhancing the quality of life for patients with severe TR, making them a viable option for those who are not candidates for conventional surgery.

Introduction

The tricuspid valve (TV) plays a crucial role in maintaining right ventricular (RV) hemodynamics. The occurrence of significant tricuspid regurgitation (TR) can result in right heart failure[1] and systemic complications that are difficult to manage clinically, often progressing to renal and hepatic failure.[2]

Over the past twenty years, TR has garnered increasing attention in the field of interventional cardiology, transforming what was once considered a "forgotten valve" into a topic of significant interest at conferences and in academic publications. This phenomenon was the result of its high prevalence, especially in the elderly population,[3] and poor prognosis during its evolution.[4] Furthermore, conventional surgical treatment of TR, although effective, has significant limitations, especially in patients with advanced stages of heart failure or at high surgical risk.[5] In recent years, there has been a considerable expansion in the development and implementation of minimally invasive percutaneous techniques, with the introduction of a variety of devices aimed at correcting TR.[6]

However, the appropriate time for intervention and the type of device suitable for each situation remains the subject of study and controversy.

The development of percutaneous techniques for TR treatment has progressed rapidly, enhancing the understanding of the disease. Consequently, this document aims to outline the new etiological and quantitative classification of TR, along with detailed indications for the most commonly utilized percutaneous treatments, emphasizing the necessary echocardiographic monitoring.

Keywords

Tricuspid Valve Insufficiency; Transcatheter Aortic Valve Replacement; Echocardiography

Mailing Address: Marcio Mendes Pereira •
UDI Hospital. Av. Prof. Carlos Cunha, 2000. Postal Code: 65076-820. Jaracti, São Luis, MA – Brazil
E-mail: marciomp50@hotmail.com
Manuscript received September 16, 2024; revised September 17, 2024; accepted September 21, 2024
Editor responsible for the review: Marcelo Tavares

DOI: https://doi.org/10.36660/abcimg.20240088i

New quantitative classification and mechanisms of tricuspid insufficiency

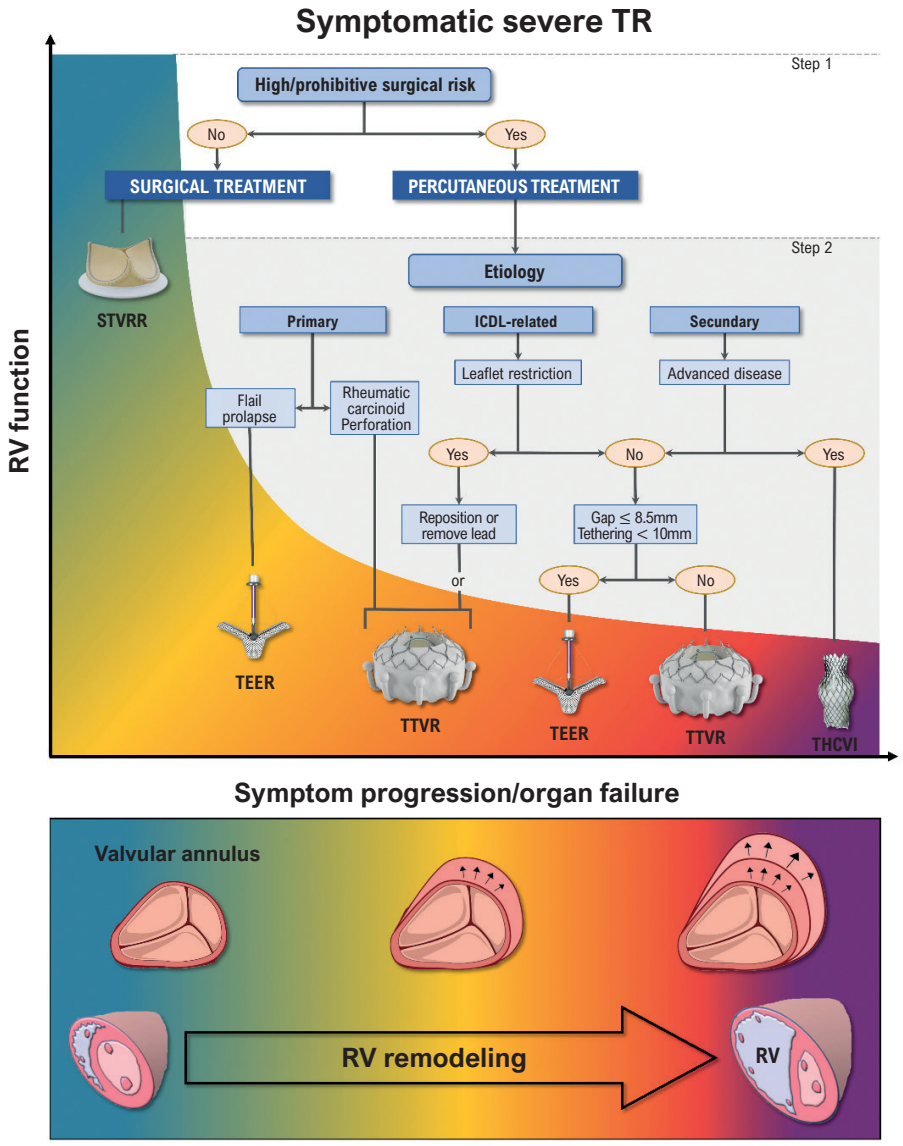
Re-quantifying TR

For a better understanding of the mechanisms of TR and the results of percutaneous procedures, a new classification of severity of TR quantification and a deep knowledge of the anatomy of the TV have become necessary.[7] Currently, only 54% of TVs actually have three cusps[8] and the degree of regurgitation is classified into five levels, as described in Table 1. This quantification is useful as a prognostic marker for the outcome of percutaneous treatment. In some cases, the reduction of torrential TR to severe TR can be considered successful.[9] Furthermore, there is an inverse relationship between symptom improvement and the five-level TR grading.[9]

New Etiological Classification of TR

Understanding the etiology of TR is essential for therapeutic planning. The Carpentier classification, created for the mitral valve, can be adapted for the TV. However, despite being very informative, especially for cardiac surgery professionals, it does not define specific mechanisms and possible percutaneous treatment methods currently available.[10] In this context, a novel etiological classification directly associated with the mechanism of TR has been proposed, categorizing the causes into secondary atrial, secondary ventricular, those

Central Illustration: Advances in Percutaneous Tricuspid Valve Treatment



Arq Bras Cardiol: Imagem cardiovasc. 2024;37(4):e20240088

STVRR: surgical tricuspid valve replacement or repair; ICDL: intracardiac device lead; TEER: transcatheter edge-to-edge repair; TTVR: transcatheter tricuspid valve replacement; THCVI: transcatheter heterotopic caval valve implantation; RV: right ventricle; TR: tricuspid regurgitation.

associated with intracardiac device leads (ICDL), and primary causes involving the valve leaflets directly. The schematic representation of each etiology is described in Figure 1.[10]

Percutaneous procedures are more rarely used in primary etiology, which is characterized by structural changes in the TV without significant cardiac or pulmonary diseases that would explain valve dysfunction. The most common causes include degenerative, congenital (such as Ebstein's anomaly and dysplasias), rheumatic diseases and injuries resulting from trauma, radiation, and carcinoid syndrome. However, primary etiology makes up only a small fraction of TR cases (10%).[11]

Conversely, the most common form of TR is secondary to RV changes (including pulmonary hypertension, pulmonary valve disorders, and RV dysfunction due to cardiomyopathies)

Table 1 – Quantification for TR at five levels (adapted from Hahn et al.[6])

Parameter	Minor	Moderate	Severe	Massive	Torrential
Vena contracta (mm)	3	3-6,9	7-13	14-20	≥21
ROA (mm²)	20	20-39	40-59	60-79	≥80
RV (ml)	30	30-44	45-59	60-74	≥75
Regurgitant fraction (%)	25	25-44	≥45		
Vena contracta 3D (mm²)	---	---	75-94	95-114	≥115

ROA: regurgitant orifice area; RV: regurgitant volume; 3D: three-dimensional echocardiogram.

or right atrial remodeling resulting from arrhythmias such as atrial fibrillation. This etiology concentrates a wide range of percutaneous procedures, with emphasis on the TriClip (Abbott Vascular, Santa Clara, CA, USA),[9] percutaneous prostheses,[12] and the *TricValve* (P+F Products+Features GmbH, Wessling, Germany).[13] The indications and evaluations for each of these procedures are described in detail in the subsequent sections. Although the two etiologies are secondary, their mechanisms are distinct, as is the prognosis, where the ventricular etiology determines a worse prognosis in relation to the atrial one.[14] Pace control is the first line of treatment for atrial etiology.[15]

Finally, the etiology associated with the presence of ICDL, such as pacemaker leads, defibrillators or resynchronizers, has been added to the new TR classification. The ICDL-related TR was first described by Mediratta et al.,[16] who observed that the device lead causes a failed movement of one of the leaflets when positioned outside the commissures and in the center of the valve leaflet edge, for which a good solution would be the adequate repositioning of the lead. However, in cases of old ICDL positioning, permanent valve damage may occur, and mere repositioning would be insufficient, requiring the use of percutaneous devices such as prosthetic implantation with ICDL positioned outside the annulus.[17]

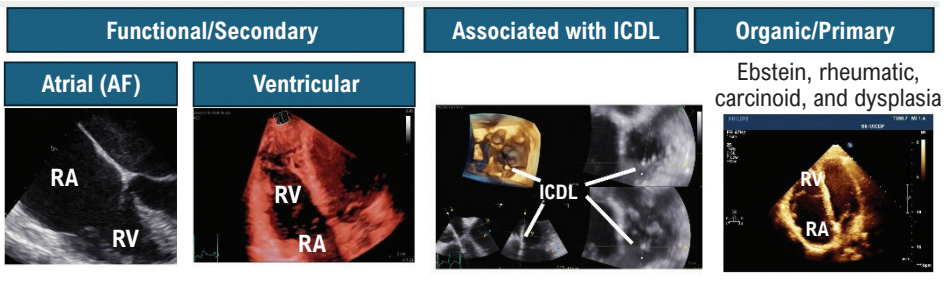
Indications for percutaneous treatment

Severe TR is strongly associated with adverse clinical outcomes[18,19] but remains undertreated.[20,21] Valvular disease guidelines recommend surgery for TR when combined with left heart procedures.[22–24] As a result, it is not uncommon for TR surgery to be rare and often delayed until patients are in advanced clinical condition, often too late to benefit from surgical intervention. This delay in addressing TR until severe symptoms of systemic congestion or RV failure emerge significantly heightens surgical risk, making isolated TR surgeries riskier compared to surgeries involving other valves.

In this context, transcatheter interventions emerge as a promising solution, offering a less invasive alternative for patients considered inoperable due to high surgical risk.[25]

For risk assessment, the TRI-SCORE scoring system (a new risk score for in-hospital mortality prediction following isolated TV surgery), based on a large multicenter database, was specifically developed to predict in-hospital mortality in patients undergoing TV surgery, outperforming traditional scores such as EuroSCORE and the Society of Thoracic Surgeons (STS) Risk Score.[26,27]

This score is based on eight parameters, as shown in Table 2. The observed and predicted in-hospital mortality rates increased from 0% to 60% and from 1% to 65%, respectively, as the score increased from 0 to 9 points or more (Figure 2). In this context, the TRI-SCORE can be a valuable tool in the



Parameter	Atrial	Ventricular	ICDL	Primary
Valve retraction	No	acentuada	usually present	Absent
Valve restriction	No	Carpentier III b	Systole/diastole	may exist (carcinoid/rheumatic)
RA dilation	severe	moderada/discreta	usually present	usually present
RV dilation	mild	acentuada	usually present	usually present
RV dysfunction	possibly mild	moderada/acentuada	usually present	may exist

Figure 1 – *Etiological classification of TR. The alterations most characteristic of the right atrium and ventricle stand out, as well as the valve movement in each of the divisions. Adapted from Hahn et al.[11] AF: atrial fibrillation; RA: right atrium; RV: right ventricle; ICDL: intracardiac device lead.*

selection of patients with the potential to benefit from both conventional surgery and transcatheter interventions.[26]

The selection of the optimal treatment requires a multidisciplinary approach (Heart Team) and a detailed assessment of the patient's valve anatomy, RV function and clinical status. The evidence to date suggests that percutaneous techniques, when properly indicated and performed, can provide significant improvements in clinical outcomes, contributing to the reduction of morbidity rates and improving the quality of life of patients with severe TR.[25]

The central figure represents a structured approach to the TR treatment, which begins with the assessment of the lesion severity and presence of symptoms, in addition to determining the patient's surgical risk. Based on these considerations, therapeutic decisions are directed, prioritizing percutaneous treatments for patients with high or prohibitive surgical risk.[28]

Step 1: Surgical risk assessment

For symptomatic patients with severe, massive, or torrential TR who have a high or prohibitive surgical risk, percutaneous treatment is the preferred option. Those who do not have these conditions or an acceptable surgical risk are referred for conventional surgical treatment.

Step 2: Determination of Etiology and Anatomical Condition

Patients eligible for percutaneous treatment are evaluated based on the etiology of their TR, classifying them as primary, secondary, or related to the use of intracardiac devices.

Primary TR: For primary TR, the approach varies according to the etiology. Patients with leaflet prolapse or flail may be candidates for transcatheter edge-to-edge repair (TEER) or transcatheter tricuspid valve replacement (TTVR). In contrast, those with TR due to carcinoid, rheumatic, or valve perforation may require TTVR.

ICDL-related TR: patients whose TR is associated with the use of intracardiac devices, such as pacemakers, should be initially evaluated for leaflet restriction. If there is no restriction, depending on the anatomical condition, TEER or TTVR repair may be considered. If not, the possibility of repositioning or removal of the electrode, or even TTVR, may be evaluated.

Secondary TR: is evaluated considering the presence of advanced disease. Patients in the advanced stage may be referred for transcatheter heterotopic caval valve implantation therapy (TricValve). In cases where the disease is not yet advanced, it is crucial to assess the coaptation failure of the leaflets and the tethering height (tent). Patients with a coaptation failure of up to 8.5 mm and a tent height of less than 1.0 cm are considered optimal candidates for TEER (TriClip). In cases where the anatomy is unfavorable, a viable option would be TTVR.

Other percutaneous approaches, such as transcatheter annuloplasty techniques, have also been explored in the treatment of secondary TR in patients with significant dilation of the tricuspid annulus but with mild to moderate tethering of the leaflets (height < 1.0 cm; tent area < 2.5 cm^2; tent volume < 3 mL measured by 3D). Devices such as the CardioBand are used to reduce the diameter of the annulus and improve leaflet coaptation. This technique is recommended for patients in whom the primary mechanism of TR is annular dilation, with a central regurgitation jet and where there is an adequate anchoring zone for the device. Initial results suggest a significant reduction in regurgitation and improvement in heart failure symptoms.[25,29,30]

Recently, the development of devices for the percutaneous treatment of TR has accelerated, providing new therapeutic options for a condition that historically had limited alternatives. While promising, many of these devices are still in the clinical trial phase. In Brazil, to date, only the TricValve and, more recently, the TriClip have been approved for use in clinical practice.

Table 2 – TRI-SCORE: Surgical risk model for in-hospital mortality after isolated TR surgery. Adapted from Dreyfus et al.[26]

Parameter	Score
Age > 70 years	1
NYHA Class III-IV	1
Signs of right-sided HF	2
Daily furosemide dose > 125 mg	2
Glomerular filtration rate < 30 mL/min	2
Elevated total bilirubin	2
LV ejection fraction < 60%	1
Moderate/severe RV dysfunction	1
TOTAL	12

HF: heart failure; NYHA: New York Heart Association; LV: left ventricle; RV: right ventricle.

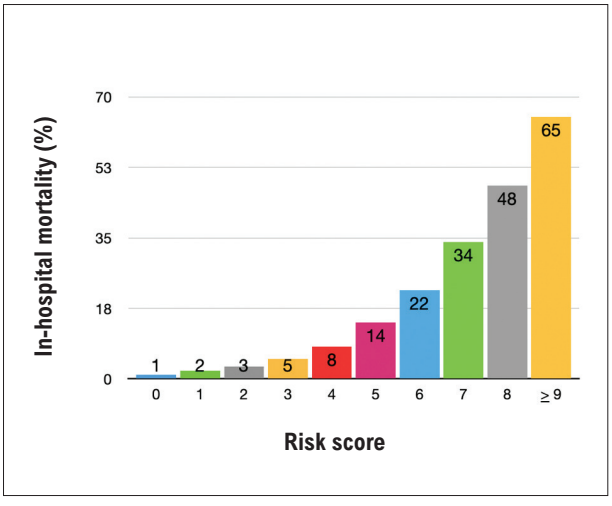


Figure 2 – *Predicted in-hospital mortality rate according to the final risk score model. Adapted from Dreyfus et al.[26]*

Transcatheter edge-to-edge treatment of the TV

The TEER of the TV is the most extensively studied percutaneous technique.5 The TriClip system is an edge-to-edge repair technique developed based on the MitraClip device (Abbott Laboratories, Abbott Park, IL, USA). The TRILUMINATE Pivotal trial was the first randomized study to evaluate this technique in an elderly patient population with high surgical risk and symptomatic TR, demonstrating the safety of the technique, a significant reduction in TR and improved quality of life.[9]

The pre-treatment evaluation of TEER consists of transthoracic (TTE) and transesophageal (TEE) echocardiography, the latter being essential since it guides the intraprocedure. Studying the TV by TEE can be challenging because it is usually in the farthest field from the esophageal position, the leaflets are thin, and there are often problems with acoustic shadowing.[31]

The main TEE windows are described below:

In the **four-chamber view** (Figure 3C), typically obtained in the mid-esophagus at an angle between 0° and 25°, the septal leaflet is easily identified as it is attached to the interventricular septum. The lateral leaflet observed may usually be the anterior one, although it can also be the posterior leaflet if the probe tip is retroflexed or advanced deeper into the esophagus. The **RV inlet/outlet window** (Figure 3A) is obtained between 60° and 90°, in which the RV inlet and outlet tracts and the aortic valve are visualized in a short axis. Similar to the mitral commissural projection, with the biplane or X-plane tool cursor directed across the TV closest to the aortic valve, the orthogonal view shows the septal and anterior leaflets, and similarly, if the cursor is directed to the left (farthest from the aortic valve), the orthogonal view shows the septal and posterior leaflets (Figure 3A). This window is often used to visualize leaflet grasp during the procedure; however, if the TV leaflets are not adequately visualized, images should be obtained from the deep esophageal view since, from this position, the interatrial septum and septal mitral annulus are excluded from the field of view. The **transgastric window** (Figure 3D) is important for screening as well as intraprocedural monitoring. The probe is advanced into the stomach and anteroflexed to obtain a short-axis image of the mid-LV. It is then pulled back until the TV leaflets are visible. The angle is rotated between 0° and 60° so that all three commissures are visualized. Adjustments in the right-left lateralization can help optimize the image. This window is very useful for assessing the size and location of the gap, which will be decisive for planning the procedure (clip location, size, and number of clips). During the procedure, this window is also valuable for guiding the clip to the desired position within the annular plane and for rotating the clip device to align it perpendicularly with the coaptation line of the respective leaflet (Figure 3F). **Three-dimensional (3D) images** should be captured at the highest possible frame rate in any of the aforementioned windows, although the commissural view is often preferred to ensure that part of the aortic valve is included in the image for orientation. The appropriate way to display the TV in 3D remains controversial.[32] However, during the procedure, it is recommended that an *en face* orientation be identical to the transgastric one, aiming to facilitate comparison and understanding of the images, by placing the interatrial septum on the right side of the screen with the aorta located at the five o'clock position (Figure 3B).[33] A very interesting alternative used during the procedure is the 3D imaging with the flexi-slice technique or multiplanar reconstruction, which allows monitoring the capture of the leaflets in real-time, providing simultaneous visualization of the three planes (Figure 3E).

The TriClip system has two main techniques: the triple hole technique, which positions the clips centrally between the septal-anterior and septal-posterior leaflets, and the bicuspidization technique, which starts with a clip at the anteroseptal commissure and continues with additional clips towards the center of the valve, also known as the zipping technique. Currently, this technique is the most viable and widely used.[33]

Proper selection of patients for TEER is essential for the success of the procedure. **Optimal factors** include coaptation failure of less than 7 mm, adequate leaflet mobility, jet located in the anteroseptal or central commissure, confined prolapse or flail, and presence of a pacemaker lead that does not restrict leaflet movement; and the **complicating factors**: coaptation failure greater than 8.5 mm, jet located in the posteroseptal or anteroposterior commissure, thickened and short leaflets, leaflet perforation, TEE with difficult acoustic window, pacemaker lead preventing leaflet movement, leaflet tent height greater than 1 cm.[34,35] Recently, a score (GLIDE score) was created to predict the immediate post-TEER procedure results with five anatomical criteria easily obtained through TEE, with 1 point added for each complexity criterion: Indicators for patient selection include an anteroseptal gap greater than 6 mm; the location of a posteroseptal, anteroposterior, or diffuse jet; limited image quality; high chordae density; and star-shaped jet morphology when viewed *en face*. The GLIDE score was able to predict procedural success, defined by a reduction in TR greater than or equal to 2 degrees and moderate or less post-procedural TR, respectively, in patients with 0 or 1 points in 91% and 97%, with 2 or 3 points in 47% and 61%, and with more than 4 points in 14% for both definitions.[36]

Percutaneous orthotopic TV implantation

The development of devices specifically designed for TTVR is currently at an early stage and is being evaluated in clinical trials.

TTVR emerges as a therapeutic option in patients with severe, symptomatic TR, despite optimized drug treatment (including high doses of diuretics) and with high and/or prohibitive surgical risk. TTVR is mainly indicated in cases of secondary TR (even for larger annuli and larger coaptation failures – in which the valve anatomy is not favorable for TEER), pacemaker-induced TR and part of primary TR. Replacement therapy is contraindicated or considered relatively contraindicated in patients with RV outflow tract obstruction, active infective endocarditis, intracardiac masses, pulmonary artery systolic pressure greater than or equal to 55 mmHg (assessed by echocardiography or right heart catheterization), a decreased left ventricular ejection fraction (LVEF < 50%), complications from other cardiac diseases requiring surgical intervention, congenital Ebstein anomaly or

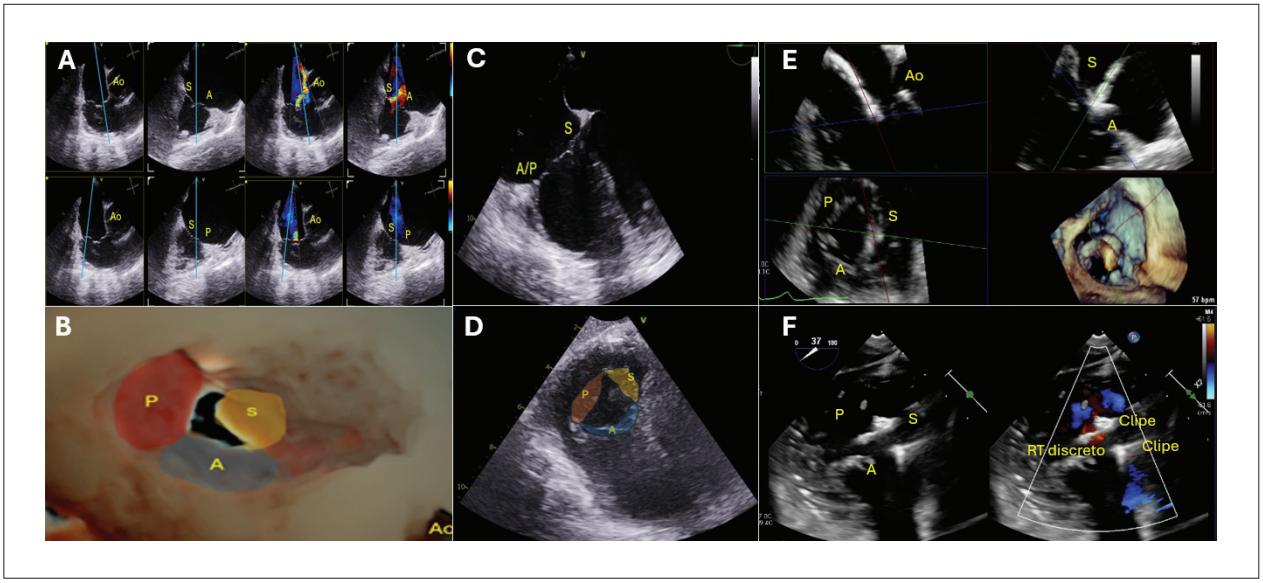


Figure 3 – *Transesophageal echocardiographic windows before and during the TEER procedure. (A) RV inflow/outflow tract windows. (B) 3D image of the TV demonstrating significant coaptation failure. (C) Four-chamber view. (D) Transgastric view. (E) Flexi-slice or multiplanar reconstruction of the TV. (F) Transgastric window with the biplanar or X-plane tool after implantation of two clips in the anteroseptal commissure with mild TR. A: anterior leaflet; S: septal leaflet; P: posterior leaflet; Ao: aorta; TR: tricuspid regurgitation. Images E and F were provided by Julien Ternacle, Bordeaux, France*

severe structural RV dysplasia, and anatomical features that are unsuitable for the approach (such as excessive dilation of the tricuspid annulus that exceeds the available transcatheter valve sizes or inadequate venous access that cannot accommodate the delivery catheter).[37,38]

There is growing interest in TTVR therapy due to its ability to eradicate TR (rather than only partial reductions seen with other transcatheter repair techniques), its ability to treat a broader range of anatomies and pathologies, and its potential to offer alternative surgical procedures valve-in-valve in the future. These potential benefits need to be weighed against the need for post-procedure therapeutic anticoagulation, a more invasive procedure, potential induction of atrioventricular block, difficulty implanting pacemakers in the future, long-term durability and risk of worsening of RV function.[39]

In general, in potential candidates for TTVR, it is of utmost importance to measure systolic pressure in the pulmonary artery and assess the size and function of the RV, as they are directly related to the estimation of risk and prognosis of these patients.[38] Sun et al.[40] excluded patients with LV dysfunction (LVEF < 50%), pulmonary hypertension (PASP ≥ 60 mmHg), RV dysfunction (TAPSE < 10 mm and FAC < 29%), untreated severe coronary artery disease, Ebstein's anomaly, congenital RV dysplasia and RV outflow obstruction. In this study, patients were followed for 12 months, with six patients having previously undergone left valvular surgery and subsequently undergoing LuX-Valve implantation for massive TR.[40]

Several orthotopic replacement systems are under clinical and preclinical investigation. Among these, four of the devices [NaviGate (NaviGate Cardiac Structures, Lake Forest, CA, USA), EVOQUE (Edwards Lifesciences), LuX-Valve (Jenscare Biotechnology, Ningbo, China) and Lux Valve Plus (Jenscare)] have published first-in-human results. These devices rely on radial force (NaviGate, EVOQUE), tricuspid leaflet engagement (all four devices) or septal insertion (LuX-Valve and Lux Valve Plus) for implantation and stability.[41]

The only therapy currently approved for commercial use in Europe and the USA is EVOQUE, while the others are still under compassionate use.

In patient selection and treatment planning, TTE is the first-line imaging modality. It plays a fundamental role, with special attention paid to the apical four-chamber image "focused" on the RV. When the image of the latter is not satisfactory, TEE is recommended.

Computed tomography (CT) is also essential in screening these patients, as it can measure the diameters related to the tricuspid annulus, as well as the angle of the interventricular septum and simulate the post-implant morphology, actively participating in the selection of the device size. The measurement of the internal diameter of the jugular vein performed by CT in cases of transjugular device implantation is also essential. The recommended diameter should exceed 8 mm.[38] In cases of devices implanted via the femoral vein, analysis of venous access is also recommended.

Cardiac magnetic resonance imaging (CMRI) can be used as an adjuvant imaging modality for assessing the TV before TTVR. It can be used for anatomical and functional assessment due to its excellent spatial resolution.[42]

The procedure is performed under general anesthesia, guided by fluoroscopy and 3D TEE. Intraoperative TEE can be used to assess the severity of regurgitation, tricuspid apparatus anatomy, ventricular function, and pulmonary artery pressure before intervention. For patients with previous mitral and/or aortic valve replacement (especially those with a mechanical valve), the TV in the midesophageal view may

be unsatisfactory due to the influence of acoustic shadowing. In this case, the deep esophageal or transgastric view can be used for monitoring and guidance purposes, and acquisition and visualization of 3D images can also be performed based on these projections. 3D TEE is essential for the success of the procedure. The main echocardiographic windows used during the procedure are the same as those used during TEER and have already been described in this article. In cases where transesophageal echocardiographic images are limited, the use of intracardiac echocardiography in association with 3D TEE may be an alternative.

As of the publication date of this article, compassionate implants of the LuX-Valve Plus device have been performed in three patients in Brazil, making them the only cases in Latin America. All three implants were successful, exhibiting low transvalvular gradients, no central insufficiency or paravalvular leaks, and excellent clinical outcomes. Below are some illustrative images of the initial Brazilian experience (Figures 5 and 6).

The LuX-Valve system (Jenscare) is a new self-expanding valve (Figure 4) made of bovine pericardium leaflet. The valve is fixed by a ventricular septal anchor (in the shape of a "bird's tongue") and tricuspid leaflet clamps (in the shape of a "rabbit's ear") and does not depend on radial force. The atrial disc consists of a self-adjusting polyester ring designed to prevent paravalvular leaks without compressing the tissue surrounding the TV. The device can be readjusted to minimize and/or prevent any potential paravalvular leaks. The first-generation LuX-Valve system (Jenscare) is implanted through the right atrium, which requires a small incision in the right chest. The second-generation LuX-Valve Plus system (Jenscare) uses a percutaneous transjugular approach and is currently in use.[38]

Post-procedure monitoring and evaluation are conducted using TTE, with primary goals including assessment of the prosthetic stent's position and stability, leaflet mobility, the presence and extent of intra- or paravalvular regurgitation, and transvalvular gradients.

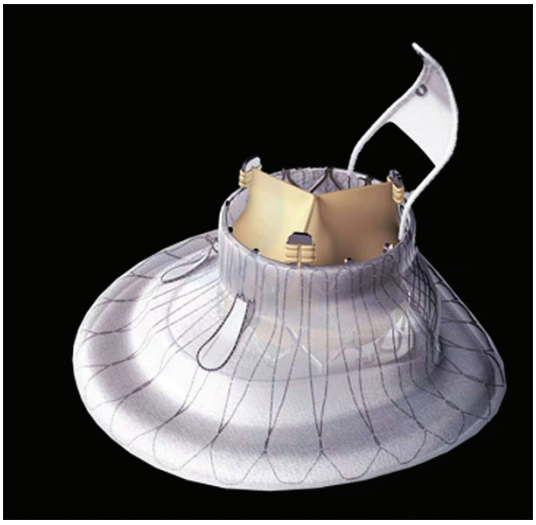


Figure 4 – *Illustrative image of the LuX-Valve Plus device, including an interventricular septal anchoring component; a self-expanding nitinol valve stent composed of an atrial disc; two clamps and a trileaflet valve prosthesis with treated bovine pericardium.*

Transcatheter implantation of heterotopic caval valve (THCVI)

Currently, transcatheter therapies for the TV primarily focus on TEER and orthotopic implantation. However, the success of these techniques depends on several anatomical criteria, which leads to the exclusion of many patients. In this context, THCVI emerges as a strategy to treat the systemic effects of severe TR,[43,44] with TricValve being the device approved in Brazil. It consists of two nitinol stents with bovine pericardium leaflets implanted in the inferior and superior vena cava.[45]

The TricValve has been tested in the combined TRICUS/TRICUS EURO cohorts, demonstrating significant functional improvement in 95% of patients at one-year follow-up, with immediate abolition of hepatic venous reverse flow.[45] Randomized studies are lacking to date.

In summary, studies involving the TricValve have included only severely symptomatic patients (NYHA functional class III or IV, or those with prior hospitalizations for heart failure within the last 12 months) despite receiving optimal medical therapy and deemed to be at high or prohibitive surgical risk for conventional tricuspid surgery. Nevertheless, patients with severe pulmonary hypertension (systolic pulmonary pressure > 65 mmHg) or significantly impaired RV function (i.e., TAPSE < 13 mm) were excluded from these studies.[46]

CT is employed for prosthesis sizing to reduce potential safety concerns. An oversizing of 10% to 40% within the belly of the superior vena cava prosthesis and in the proximal part of the inferior vena cava prosthesis is desirable to optimize fixation and sealing. TTE or ETE plays an important role during implantation and subsequent monitoring. Prosthesis implantation in the superior vena cava is basically guided by scopy. Following the release of the prosthesis, echocardiography is used to evaluate blood flow via Doppler imaging and to check for the presence of paraprosthetic leaks. Prosthesis positioning in the inferior vena cava involves a protrusion into the right atrium of no more than 15 mm, guided by echocardiography, to reduce the risk of perivalvular leak. Once the prosthesis is deployed, the flow through the suprahepatic veins is analyzed, focusing on the disappearance of reverse flow, the identification of any paraprosthetic leaks, and ensuring there is no stenosis of the veins due to the prosthesis (Figure 7).[47]

In comparison to percutaneous left heart procedures, transcatheter heart valve intervention (THCVI) is generally very well tolerated hemodynamically during the procedure. However, after implantation, there is a sudden physiological change marked by a substantial increase in RV afterload due to reduced retrograde flow to the cavae, an acute rise in right atrial pressure, and an increase in cardiac output, assuming RV function is maintained. This is accompanied by significant systemic decongestion, with particularly positive effects observed in the liver. The individual response to these changes is variable and will largely depend on baseline RV

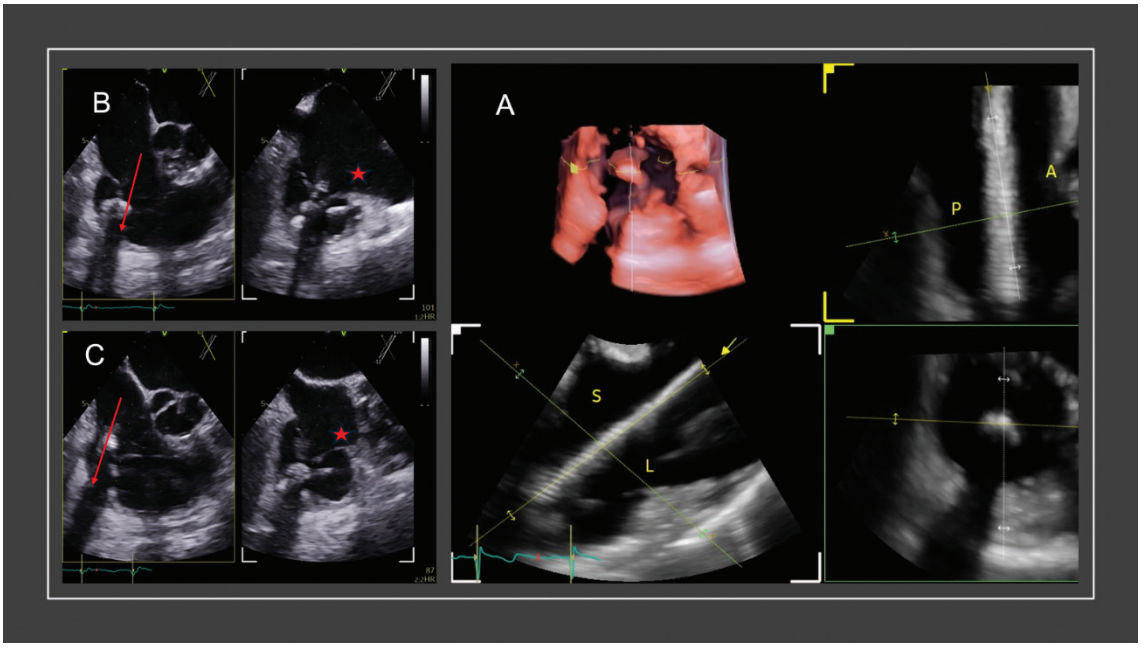


Figure 5 – *I3D TEE image with MPR: orientation and coaxiality of the delivery system so that it is positioned in the central axis of the TV and perpendicular to the annular plane (A); Grasper confirmation. RV inflow/outflow tract images, mid-esophagus using the X-plane tool (red arrow on the left image): the right image confirms the TV's anterior leaflet position above the clip (B); Grasper confirmation. RV inflow/outflow tract images, mid-esophagus using the X-plane tool (red arrow on the left image): the right image confirms the TV's posterior leaflet position above the clip (C).*

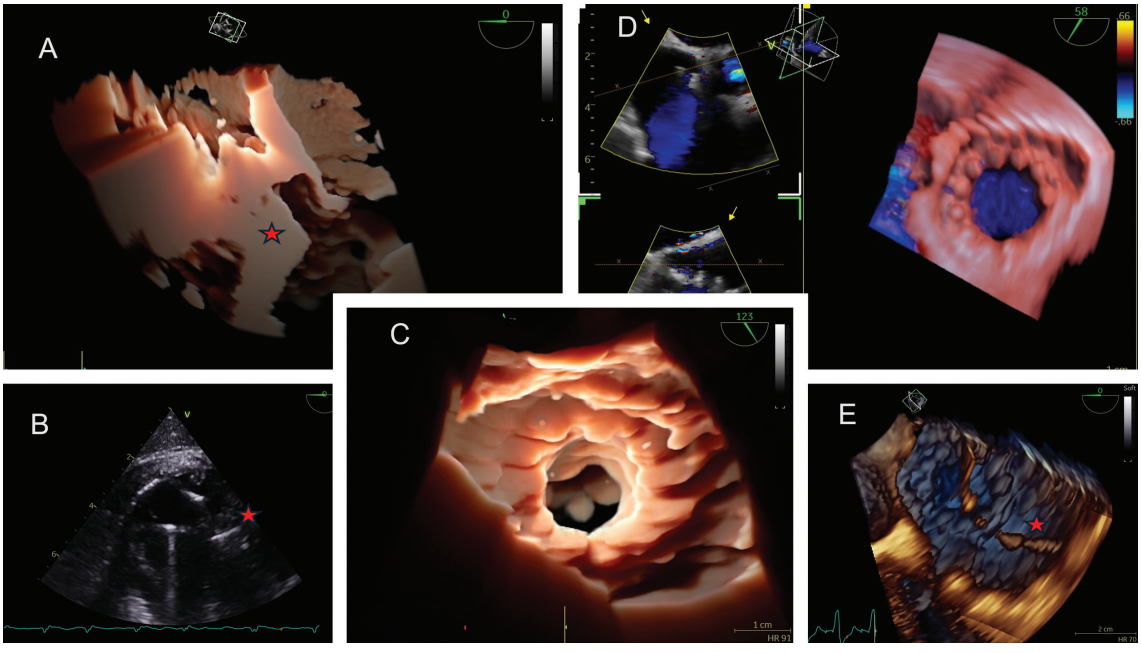


Figure 6 – *Real-time 3D TEE image, mid-esophagus 4C, showing septal anchoring (red star) (A); Transgastric ventricular short axis view (SAX) showing septal anchoring (red star) (B); 3D TEE image of the LuX-Valve Plus as seen from the right atrium (RA) (C); 3D TEE image with color flow mapping of the LuX-Valve Plus seen from the right atrium with laminar spectral flow and absence of paravalvular insufficiency and/or leak (D); 3D TEE image of the LuX-Valve Plus seen from the right atrium in a patient with a pacemaker (red star identifying the pacemaker wire) (E).*

function and its ability to adapt to increased afterload, baseline pulmonary artery pressures, and left ventricular function.[46]

Conclusion

The progression of percutaneous interventions for treating TR represents a significant advancement in the management of patients at high surgical risk. The new etiological classification, along with the implementation of advanced imaging techniques, enhances diagnostic and therapeutic accuracy, facilitating a more personalized treatment approach. Although preliminary results show significant improvements, the durability of therapeutic solutions and their long-term impact require further investigation. These developments underscore the growing importance of multidisciplinary strategies that can transform the disease outcome by combining technical sophistication with scientific knowledge.

Author Contributions

Conception and design of the research, acquisition of data, writing of the manuscript and critical revision of the manuscript for intellectual content: Pereira MM, Otto ME, Netto FM, Esteves F.

Potential Conflict of Interest

I declare that there is a potential conflict of interest for the following authors: Pereira MM - Proctor in MitraClip echocardiography by Abbott Laboratories; Netto FM – Proctor in MitraClip echocardiography by Abbott Laboratories; and Esteves F – Proctor in MitraClip echocardiography by Abbott Laboratories and proctor in echocardiography by Edwards Lifesciences.

Sources of Funding

There were no external funding sources for this study.

Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

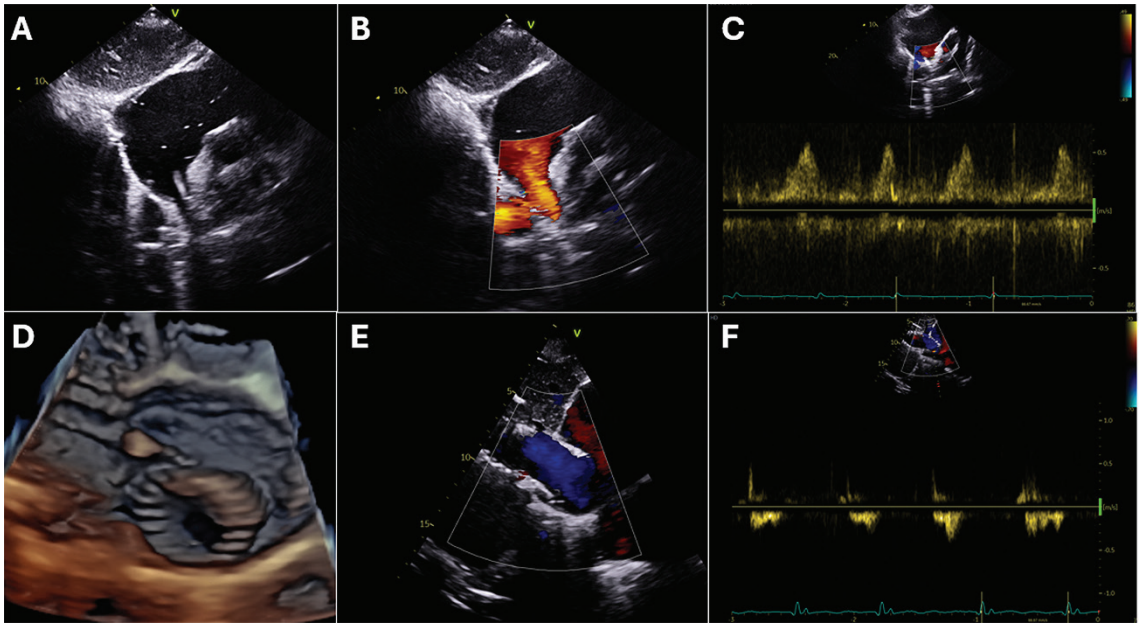


Figure 7 – *Evaluation of the TricValve after implantation by TTE. (A) Visualization of the superior caval prosthesis through the subcostal window. (B) Color Doppler with antegrade flow through the superior caval prosthesis. (C) Pulsed Doppler of the flow through the superior caval prosthesis. (D) 3D image of the inferior caval prosthesis demonstrating the 1.5 cm protrusion into the right atrium. (E) Color Doppler with antegrade flow through the inferior caval prosthesis. (F) Pulsed Doppler of the flow through the superior caval prosthesis.*

References

1. Benfari G, Antoine C, Miller WL, Thapa P, Topilsky Y, Rossi A, et al. Excess Mortality Associated with Functional Tricuspid Regurgitation Complicating Heart Failure with Reduced Ejection Fraction. Circulation. 2019;140(3):196-206. doi: 10.1161/CIRCULATIONAHA.118.038946.
2. Tarasoutchi F, Montera MW, Ramos AIO, Sampaio RO, Rosa VEE, Accorsi TAD, et al. Update of the Brazilian Guidelines for Valvular Heart Disease - 2020. Arq Bras Cardiol. 2020 Oct;115(4):720-75. doi: 10.36660/abc.20201047.
3. Messika-Zeitoun D, Baumgartner H, Burwash IG, et al. Unmet Needs in Valvular Heart Disease. Eur Heart J 2023;44(21):1862–1873; doi: 10.1093/eurheartj/ehad121.
4. Topilsky Y, Nkomo VT, Vatury O, Michelena HI, Letourneau T, Suri RM, et al. Clinical Outcome of Isolated Tricuspid Regurgitation. JACC Cardiovasc Imaging. 2014;7(12):1185-94. doi: 10.1016/j.jcmg.2014.07.018.
5. Ambrosino M, Sangoi M, Monzer N, Irving B, Fiorilli P, Khazan B, et al. Tricuspid Regurgitation: A Review of Current Interventional Management. J Am Heart Assoc. 2024;13(6):e032999. doi: 10.1161/JAHA.123.032999.
6. Hahn RT, Lawlor MK, Davidson CJ, Badhwar V, Sannino A, Spitzer E, et al. Tricuspid Valve Academic Research Consortium Definitions for Tricuspid Regurgitation and Trial Endpoints. Eur Heart J. 2023;44(43):4508-32. doi: 10.1093/eurheartj/ehad653.
7. Hahn RT, Thomas JD, Khalique OK, Cavalcante JL, Praz F, Zoghbi WA. Imaging Assessment of Tricuspid Regurgitation Severity. JACC Cardiovasc Imaging. 2019;12(3):469-90. doi: 10.1016/j.jcmg.2018.07.033.
8. Hahn RT, Weckbach LT, Noack T, Hamid N, Kitamura M, Bae R, et al. Proposal for a Standard Echocardiographic Tricuspid Valve Nomenclature. JACC Cardiovasc Imaging. 2021;14(7):1299-305. doi: 10.1016/j.jcmg.2021.01.012.
9. Sorajja P, Whisenant B, Hamid N, Naik H, Makkar R, Tadros P, et al. Transcatheter Repair for Patients with Tricuspid Regurgitation. N Engl J Med. 2023;388(20):1833-42. doi: 10.1056/NEJMoa2300525.
10. Hahn RT, Badano LP, Bartko PE, Muraru D, Maisano F, Zamorano JL, et al. Tricuspid Regurgitation: Recent Advances in Understanding Pathophysiology, Severity Grading and Outcome. Eur Heart J Cardiovasc Imaging. 2022;23(7):913-29. doi: 10.1093/ehjci/jeac009.
11. Bienstock SW, Stone GW. From TriValve to TRILUMINATE to TRISCEND: what have we learned? Eur Heart J. 2023;44(46):4874-7. doi: 10.1093/eurheartj/ehad622.
12. Estévez-Loureiro R, Sánchez-Recalde A, Amat-Santos IJ, Cruz-González I, Baz JA, Pascual I, et al. 6-Month Outcomes of the TricValve System in Patients with Tricuspid Regurgitation: The TRICUS EURO Study. JACC Cardiovasc Interv. 2022;15(13):1366-77. doi: 10.1016/j.jcin.2022.05.022.
13. Muraru D, Previtero M, Ochoa-Jimenez RC, Guta AC, Figliozzi S, Gregori D, et al. Prognostic Validation of Partition Values for Quantitative Parameters to Grade Functional Tricuspid Regurgitation Severity by Conventional Echocardiography. Eur Heart J Cardiovasc Imaging. 2021;22(2):155-65. doi: 10.1093/ehjci/jeaa282.
14. Patlolla SH, Schaff HV, Nishimura RA, Stulak JM, Chamberlain AM, Pislaru SV, et al. Incidence and Burden of Tricuspid Regurgitation in Patients with Atrial Fibrillation. J Am Coll Cardiol. 2022;80(24):2289-98. doi: 10.1016/j.jacc.2022.09.045.
15. Mediratta A, Addetia K, Yamat M, Moss JD, Nayak HM, Burke MC, et al. 3D Echocardiographic Location of Implantable Device Leads and Mechanism of Associated Tricuspid Regurgitation. JACC Cardiovasc Imaging. 2014;7(4):337-47. doi: 10.1016/j.jcmg.2013.11.007.
16. Gelves-Meza J, Lang RM, Valderrama-Achury MD, Zamorano JL, Vargas-Acevedo C, Medina HM, et al. Tricuspid Regurgitation Related to Cardiac Implantable Electronic Devices: An Integrative Review. J Am Soc Echocardiogr. 2022;35(11):1107-22. doi: 10.1016/j.echo.2022.08.004.
17. Topilsky Y, Nkomo VT, Vatury O, Michelena HI, Letourneau T, Suri RM, et al. Clinical Outcome of Isolated Tricuspid Regurgitation. JACC Cardiovasc Imaging. 2014;7(12):1185-94. doi: 10.1016/j.jcmg.2014.07.018.
18. Nath J, Foster E, Heidenreich PA. Impact of Tricuspid Regurgitation on Long-term Survival. J Am Coll Cardiol. 2004;43(3):405-9. doi: 10.1016/j.jacc.2003.09.036.
19. Taramasso M, Gavazzoni M, Pozzoli A, Dreyfus GD, Bolling SF, George I, et al. Tricuspid Regurgitation: Predicting the Need for Intervention, Procedural Success, and Recurrence of Disease. JACC Cardiovasc Imaging. 2019;12(4):605-21. doi: 10.1016/j.jcmg.2018.11.034.
20. Stuge O, Liddicoat J. Emerging Opportunities for Cardiac Surgeons within Structural Heart Disease. J Thorac Cardiovasc Surg. 2006;132(6):1258-61. doi: 10.1016/j.jtcvs.2006.08.049.
21. Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin JP 3rd, Gentile F, et al. 2020 ACC/AHA Guideline for the Management of Patients with Valvular Heart Disease: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. J Am Coll Cardiol. 2021;77(4):e25-e197. doi: 10.1016/j.jacc.2020.11.018.
22. Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, et al. 2021 ESC/EACTS Guidelines for the Management of Valvular Heart Disease. Eur Heart J. 2022;43(7):561-632. doi: 10.1093/eurheartj/ehab395.
23. Tarasoutchi F, Montera MW, Ramos AIO, Sampaio RO, Rosa VEE, Accorsi TAD, et al. Update of the Brazilian Guidelines for Valvular Heart Disease - 2020. Arq Bras Cardiol. 2020;115(4):720-75. doi: 10.36660/abc.20201047.
24. Maisano F, Hahn R, Sorajja P, Praz F, Lurz P. Transcatheter Treatment of the Tricuspid Valve: Current Status and Perspectives. Eur Heart J. 2024;45(11):876-94. doi: 10.1093/eurheartj/ehae082.
25. Dreyfus J, Audureau E, Bohbot Y, Coisne A, Lavie-Badie Y, Bouchery M, et al. TRI-SCORE: A New Risk Score for In-hospital Mortality Prediction after Isolated Tricuspid Valve Surgery. Eur Heart J. 2022;43(7):654-62. doi: 10.1093/eurheartj/ehab679.
26. Gröger M, Friedl S, Ouerghemmi D, Tadic M, Bruß E, Felbel D, et al. TRI-SCORE is Superior to EuroSCORE II and STS-Score in Mortality Prediction Following Transcatheter Edge-to-edge Tricuspid Valve Repair. Clin Res Cardiol. 2023;112(10):1436-45. doi: 10.1007/s00392-023-02246-9.
27. Praz F, Muraru D, Kreidel F, Lurz P, Hahn RT, Delgado V, et al. Transcatheter Treatment for Tricuspid Valve Disease. EuroIntervention. 2021;17(10):791-808. doi: 10.4244/EIJ-D-21-00695.
28. Utsunomiya H, Itabashi Y, Mihara H, et al. Usefulness of 3D echocardiographic parameters of tricuspid valve morphology to predict residual tricuspid regurgitation after tricuspid annuloplasty. Eur Heart J Cardiovasc Imaging 2017;18(7):809–817; doi: 10.1093/ehjci/jew323.
29. Fukuda S, Song JM, Gillinov AM, et al. Tricuspid valve tethering predicts residual tricuspid regurgitation after tricuspid annuloplasty. Circulation 2005;111(8):975–979; doi: 10.1161/01.CIR.0000156449.49998.51.
30. Bae RY. A Review of the Key Images Required for Transcatheter Tricuspid Valve Repair Screening and a Successful Procedure. n.d.
31. Schlossbauer SA, Faletra FF, Paiocchi VL, et al. Multimodality Imaging of the Anatomy of Tricuspid Valve. J Cardiovasc Dev Dis 2021;8(9); doi: 10.3390/jcdd8090107.
32. Muntané-Carol G, Alperi A, Faroux L, et al. Transcatheter Tricuspid Valve Intervention: Coaptation Devices. Front Cardiovasc Med 2020;7; doi: 10.3389/fcvm.2020.00139.
33. Matli K, Mahdi A, Zibara V, et al. Transcatheter Tricuspid Valve Intervention Techniques and Procedural Steps for the Treatment of Tricuspid Regurgitation: A Review of the Literature. Open Heart 2022;9(1); doi: 10.1136/openhrt-2022-002030.

34. Besler C, Orban M, Rommel KP, et al. Predictors of Procedural and Clinical Outcomes in Patients With Symptomatic Tricuspid Regurgitation Undergoing Transcatheter Edge-to-Edge Repair. JACC Cardiovasc Interv 2018;11(12):1119–1128; doi: 10.1016/j.jcin.2018.05.002.

35. Gerçek M, Narang A, Körber MI, et al. GLIDE Score: Scoring System for Prediction of Procedural Success in Tricuspid Valve Transcatheter Edge-to-Edge Repair. JACC Cardiovasc Imaging 2024;17(7):729–742; doi: 10.1016/j.jcmg.2024.04.008.

36. Goldberg YH, Ho E, Chau M, et al. Update on Transcatheter Tricuspid Valve Replacement Therapies. Front Cardiovasc Med 2021;8; doi: 10.3389/fcvm.2021.619558.

37. Wei X, Li X, Liang Y, et al. Transcatheter Tricuspid Valve Replacement with LuX-Valve Device: Overview of Key Echocardiographic Considerations. Catheterization and Cardiovascular Interventions 2024; doi: 10.1002/ccd.31082.

38. Seligman H, Vora AN, Haroian NQ, et al. The Current Landscape of Transcatheter Tricuspid Valve Intervention. Journal of the Society for Cardiovascular Angiography and Interventions 2023;2(6); doi: 10.1016/j.jscai.2023.101201.

39. Sun Z, Li H, Zhang Z, et al. Twelve-month outcomes of the LuX-Valve for transcatheter treatment of severe tricuspid regurgitation. EuroIntervention 2021;17(10):818–826; doi: 10.4244/EIJ-D-21-00095.

40. Liu Y, Li W, Zhou D, et al. Step-by-Step Transesophageal Echocardiographic Guidance for Transjugular Transcatheter Tricuspid Valve Replacement with a Radial Force-Independent Bioprosthesis. Quant Imaging Med Surg 2024;14(1):1061–1069; doi: 10.21037/qims-23-218.

41. Demir OM, Regazzoli D, Mangieri A, et al. Transcatheter Tricuspid Valve Replacement: Principles and Design. Front Cardiovasc Med 2018;5; doi: 10.3389/fcvm.2018.00129.

42. Estévez-Loureiro R, Sánchez-Recalde A, Amat-Santos IJ, et al. 6-Month Outcomes of the TricValve System in Patients With Tricuspid Regurgitation: The TRICUS EURO Study. JACC Cardiovasc Interv 2022;15(13):1366–1377; doi: 10.1016/j.jcin.2022.05.022.

43. Lauten A, Dreger H, Laule M, et al. Caval Valve Implantation. Interv Cardiol Clin 2018;7(1):57–63; doi: 10.1016/j.iccl.2017.08.008.

44. Blasco-Turrión S, Briedis K, Estévez-Loureiro R, et al. Bicaval TricValve Implantation in Patients With Severe Symptomatic Tricuspid Regurgitation: 1-Year Follow-Up Outcomes. JACC Cardiovasc Interv 2024;17(1):60–72; doi: 10.1016/j.jcin.2023.10.043.

45. Altisent OAJ, Benetis R, Rumbinaite E, et al. Caval Valve Implantation (CAVI): An Emerging Therapy for Treating Severe Tricuspid Regurgitation. J Clin Med 2021;10(19); doi: 10.3390/jcm10194601.

46. Di Mauro M, Guarracini S, Mazzocchetti L, et al. Transcatheter bicaval valve system for the treatment of severe isolated tricuspid regurgitation. Features from a single-Centre experience. Int J Cardiol 2024;402; doi: 10.1016/j.ijcard.2024.131864.